Squark Production with R-symmetry Beyond NLO at the LHC

Fausto Frisenna

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SUSY 2024: Theory meets Experiment

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Outline

- MRSSM: motivation and phenomenology at the LHC;

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- Soft gluon resummations;

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- Soft gluon resummations;
- Results and comparison wrt MSSM.

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- The Minimal R-symmetric Supersymmetric Standard Model (MRSSM) postulates a global U(1) R-symmetry [Fayet (1975)][Salam, Strathdee (1975)] under which SM states are uncharged, while SUSY particles such as squarks and gluinos are charged;

Motivation

- At the LHC, ongoing searches for Beyond the Standard Models physics;
- SUSY can be realized in several distinct ways with different properties;
- The Minimal R-symmetric Supersymmetric Standard Model (MRSSM) postulates a global U(1) R-symmetry [Fayet (1975)][Salam, Strathdee (1975)] under which SM states are uncharged, while SUSY particles such as squarks and gluinos are charged;
- The MRSSM, in contrast with the MSSM, has a higher degree of symmetry and, as a result, predicts more particles but has fewer free parameters.

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- EW and Higgs sectors new interactions:
  - that push the Higgs boson mass up to the observed value for smaller values of top-squark masses than in the MSSM [Bertuzzo, Frugiuele, Gregoire, Ponton (2015)][Dießner, Kalinowski, Kotlarski, Stöckinger (2014)][Diessner, Kalinowski, Kotlarski, Stöckinger (2015)][Diessner, Kalinowski, Kotlarski, Stöckinger (2016)] [Kalinowski, Kotlarski (2024)];
  - that can contribute to the W-boson mass [Dießner, Kalinowski, Kotlarski, Stöckinger (2014)][Diessner, Kalinowski, Kotlarski, Stöckinger (2016)][Athron, Bach, Jacob, Kotlarski, Stöckinger, Voigt (2022)];
- possible dark matter candidate [Belanger, Benakli, Goodsell, Moura, Pukhov (2009)][Chun, Park, Scopel (2010)][Buckley, Hooper, Kumar (2013)] in particular with light single Higgs [Diessner, Kalinowski, Kotlarski, Stöckinger (2016)][Kalinowski, Kotlarski (2024)];
- colour-octet scalar [Choi, Drees, Kalinowski, Kim, Popenda, Zerwas (2009)][Plehn, Tait (2009)][Goncalves-Netto, Lopez-Val, Mawatari, Plehn, Wigmore (2012)][Kotlarski (2017)][Darmé, Fuks, Goodsell (2018)] and Dirac gauginos [Choi, Kalinowski, Kim, Popenda (2009)][Choi, Choudhury, Freitas, Kalinowski, Kim, Zerwas (2010)][Chalons, Goodsell, Kraml, Reyes-González, Williamson (2019)];
- flavour physics properties in the lepton and top sectors [Dudas, Goodsell, Heurtier, Tziveloglou (2014)][Fok, Kribs (2010)][Herquet, Knegjens, Laenen (2010)] including $(g-2)_\mu$ [Kotlarski, Stöckinger, Stöckinger-Kim (2019)].

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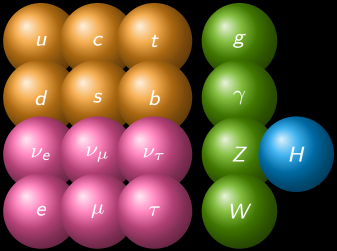
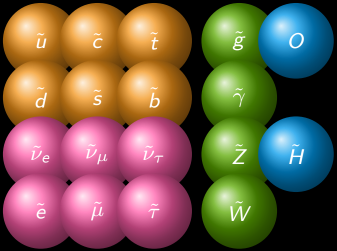
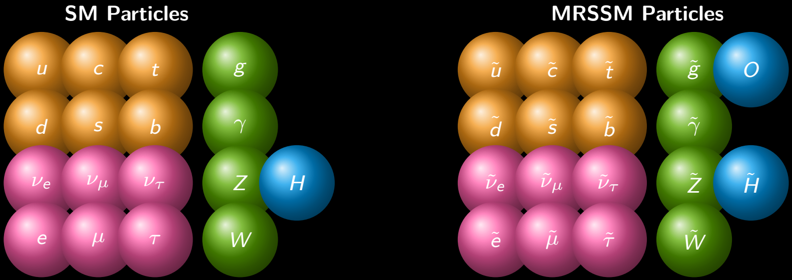
Minimal R-symmetric Supersymmetric Standard Model

SM Particles



MRSSM Particles





- $\tilde{q}_L$ part of chiral supermultiplets with $\mathrm{R} = +1$;
- $\tilde{q}_R$ part of antichiral supermultiplets with $\mathrm{R} = -1$;
- $\tilde{g}_L$ are Dirac fermions with $\mathrm{R} = +1$;
- $\tilde{g}_L$ and $\bar{\tilde{g}}_R$ behave like their MSSM counterparts;
- spin-0 colour octets O: scalar gluons.

[Kribs, Poppitz, Weiner (2008)]

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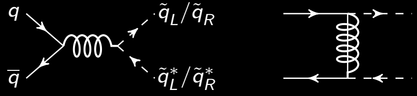
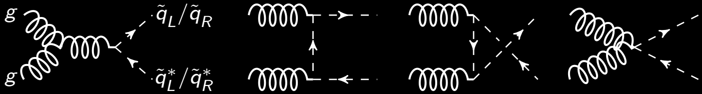
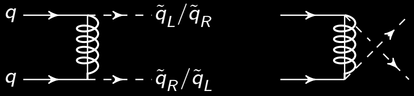
LO Squark-(anti)squark production in the MRSSM



(a) quark channel squark-antisquark;



(b) gluon channel squark-antisquark;



(c) quark channel squark-squark.

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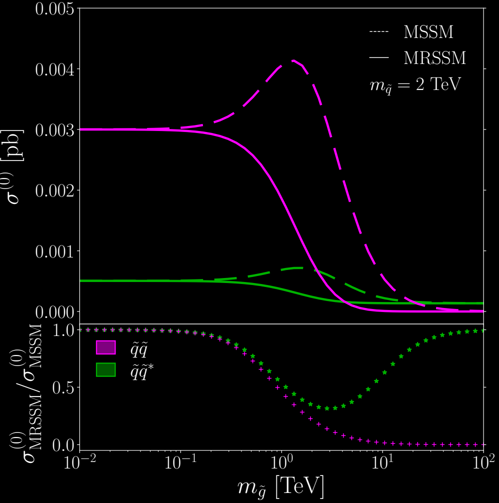

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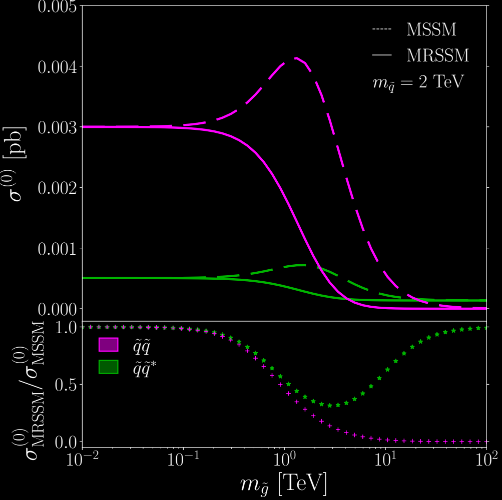

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- $m_{\tilde{g}} \to 0$: Dirac vs Majorana nature become negligible;

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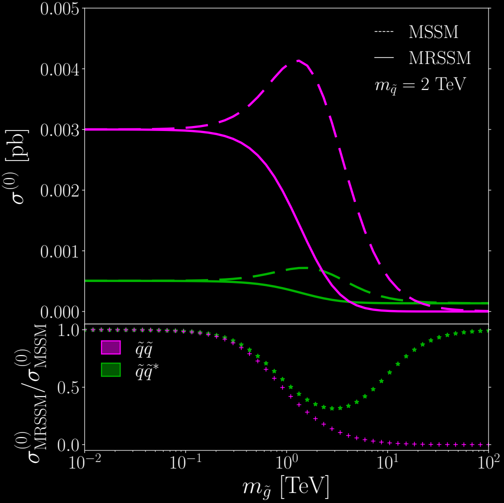

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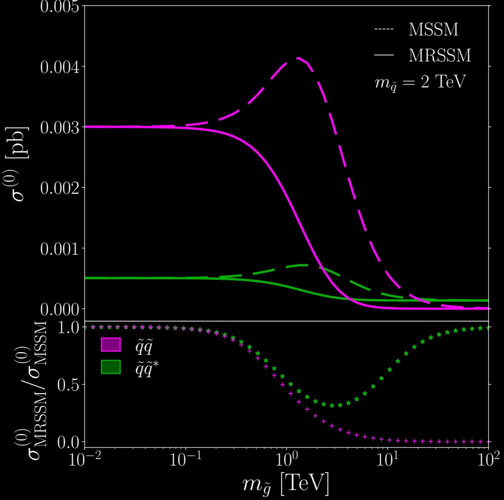

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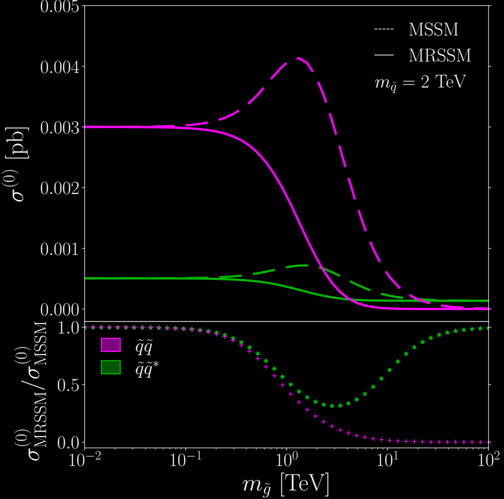

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  - MRSSM: $\sigma^{(0)}_{\tilde{q}\tilde{q}} \propto m_{\tilde{g}}^{-4}$;
  - MSSM: $\sigma^{(0)}_{\tilde{q}\tilde{q}} \propto m_{\tilde{g}}^{-2}$;

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Perturbative calculations of the cross-section

- Perturbative expansion of the cross-section:

$$\sigma = \sum_n \alpha_S^n\, c_n = c_0 + \alpha_S\, c_1 + \alpha_S^2\, c_2 + \dots \quad \text{with} \quad c_n = a_n + \sum_{k=0}^{2n} b_{nk} L^k; \quad \text{and} \quad L^k = \ln^k\left(\beta^2\right);$$

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Aim: improve the NLO calculation [Diessner, Kotlarski, Liebschner, Stöckinger (2017)] by adding resummation corrections.

- Resummation is carried out in Mellin space where the cross-section factories:

$$\tilde{\hat{\sigma}}^{(\mathrm{res})}_{ij\to jk} = \sum \tilde{H}_{ij\to jk,I} \times \tilde{\Delta}_i \tilde{\Delta}_j \times \tilde{S}_{ij\to jk,I};$$

where the Mellin transform is:

$$\tilde{f}(N) := \int_0^1 dx\, x^{N-1} f(x);$$

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- $\tilde{\Delta}_i \tilde{\Delta}_j$: resums logs from soft-collinear radiation;
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[Kodaira, Trentadue (1982)][Sterman (1987)][Catani, D'Emilio, Trentadue (1988)][Catani, Trentadue (1989)][Kidonakis, Sterman (1996)][Contopanagos, Laenen, Sterman (1997)][Kidonakis, Oderda, Sterman (1998)][Catani, De Florian, Grazzini (2001)][Moch, Vermaseren, Vogt (2004)][Beneke, Falgari, Schwinn (2010)][Czakon, Mitov, Sterman (2009)][Ferroglia, Neubert, Pecjak, Yang (2009)]...

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Identical color structure as the MSSM: known exponential functions used as for the MSSM [Kulesza, Motyka (2009)][Kulesza, Motyka (2009)][Beenakker, Brensing, Kramer, Kulesza, Laenen, Niessen (2010)][Beenakker, Brensing, Kramer, Kulesza, Laenen, Niessen (2010)][Beenakker, Brensing, Kramer, Kulesza, Laenen, Niessen (2012)][Beenakker, Janssen, Lepoeter, Krämer, Kulesza, Laenen, Niessen, Thewes, Van Daal (2013)][Beenakker, Borschensky, Krämer, Kulesza, Laenen, Theeuwes, Thewes (2014)][Beenakker, Borschensky, Heger, Krämer, Kulesza, Laenen (2016)][Beenakker, Borschensky, Krämer, Kulesza, Laenen (2016)].

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Calculations of the matching coefficient

In the absolute mass threshold up to NNLL, the hard functions factorize:

$$\tilde{H}_{ij\to jk,I} = \tilde{\hat{\sigma}}^{(0)}_{ij\to\tilde{q}\tilde{q}^{(*)},I}(N,\{m^2\},\mu^2)\left(1+\frac{\alpha_S}{\pi}\,C^{(1)}_{ij\to\tilde{q}\tilde{q}^{(*)},I}(N,\{m^2\},\mu^2)\right)$$

the one-loop matching coefficients, $C^{(1)}$, must be calculated anew for MRSSM.

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- obtained either by expanding the full NLO in β or calculating the real and virtual corrections in the threshold limit and summing them up [Beenakker, Brensing, Kramer, Kulesza, Laenen, Niessen (2012)]:

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- the real contributions: derived for any $2\to 2$ process with massive coloured particles in the final state [Beenakker, Janssen, Lepoeter, Krämer, Kulesza, Laenen, Niessen, Thewes, Van Daal (2013)];
- the virtual contributions: needed to be calculated;

- we built a subroutine to color-decompose the amplitude squared at the loop level inside the FeynArts/FormCalc [Hahn, Perez-Victoria (1999)][Hahn (2001)];

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- considering only the terms that do not contain powers of $\ln N$.

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- divided the Mellin-transformed result by the Mellin-LO at the threshold;
- considering only the terms that do not contain powers of $\ln N$.

The one-loop matching coefficients can schematically represent by:

$$\frac{\alpha_s}{\pi} C^{(1)}_{gg\to\tilde{q}\tilde{q}^*,I} = \left.\frac{\tilde{\hat{\sigma}}^{(1,\mathrm{th})}_{gg\to\tilde{q}\tilde{q}^*,I}}{\tilde{\hat{\sigma}}^{(0,\mathrm{th})}_{gg\to\tilde{q}\tilde{q}^*,I}}\right|_{\ln N-\text{independent}}$$

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- we built a sub … level inside the FeynArts/For…
- MRSSM mod…)];
- the one-loop … ger (2017)];
- the amplitude … integrals;
- the Passarino-…
- integrated ove…
- combined real…
- divided the M…
- considering or…

The one-loop mat…

$$\mathcal{C}^{(1)}_{\mathrm{MSSM},1} = \mathrm{Re}\left\{-4 + \frac{11\pi^2}{12} + 6\gamma_{\mathrm{E}}^2 + 6\gamma_{\mathrm{E}}\log\left(\frac{\mu_F^2}{4m_{\tilde{q}}^2}\right) + \frac{23}{6}\log\left(\frac{\mu_R^2}{\mu_F^2}\right) - \frac{4m_{\tilde{g}}^2}{3m_{\tilde{q}}^2} + \right.$$
$$+\frac{2}{3}\left(1-\frac{m_{\tilde{g}}^4}{m_{\tilde{q}}^4}\right)\log\left(\frac{m_{\tilde{g}}^2-m_{\tilde{q}}^2}{m_{\tilde{g}}^2+m_{\tilde{q}}^2}\right) - \frac{3m_{\tilde{g}}^2}{2m_{\tilde{q}}^2}\log^2\left(\frac{2m_{\tilde{q}}\left(\sqrt{m_{\tilde{q}}^2-m_{\tilde{g}}^2}-m_{\tilde{q}}\right)}{m_{\tilde{g}}^2}+1\right) +$$
$$\left. + \frac{3\left(m_{\tilde{g}}^2+m_{\tilde{q}}^2\right)}{2m_{\tilde{q}}^2}\left[\mathrm{Li}_2\left(-\frac{m_{\tilde{q}}^2}{m_{\tilde{g}}^2}\right) - \mathrm{Li}_2\left(\frac{m_{\tilde{q}}^2}{m_{\tilde{g}}^2}\right)\right]\right\}.$$

$$\mathcal{C}^{(1)}_{\mathrm{MRSSM},1} - \mathcal{C}^{(1)}_{\mathrm{MSSM},1} = \mathrm{Re}\left\{\frac{2}{3}m_{\tilde{g}}^2\left(\frac{\pi^2}{m_{O_s}^2}+\frac{4}{m_{\tilde{q}}^2}\right) + \left[3A_1\left(m_{\tilde{q}}^2,m_{\tilde{g}}^2,m_{O_s}^2\right) + A_4\left(m_{\tilde{q}}^2,m_{\tilde{g}}^2,m_{O_s}^2\right)\right]m_{O_s}^2\right.$$
$$\left. + 8A_4\left(m_{\tilde{q}}^2,m_{\tilde{g}}^2,m_{O_s}^2\right)m_{\tilde{q}}^2 + 6A_5\left(m_{\tilde{q}}^2,m_{\tilde{g}}^2,m_{O_s}^2\right) - 8A_7\left(m_{\tilde{q}}^2,m_{\tilde{g}}^2,m_{O_s}^2\right)\right\}.$$

$$A_1\left(m_{\tilde{q}}^2,m_{\tilde{g}}^2,m_{O_s}^2\right) = \frac{m_{\tilde{g}}^2 m_{O_s}^2}{2m_{\tilde{q}}^2(m_{O_s}^4-3m_{O_s}^2m_{\tilde{q}}^2+2m_{\tilde{q}}^4)}\left\{L_{14}^2 - L_{13}^2 + \right.$$
$$+2\left[-\mathrm{Li}_2\left(\frac{2(m_{O_s}^2-m_{\tilde{q}}^2)}{m_{O_s}(m_{O_s}+\tilde{r}^-_{O_s})}\right) + \mathrm{Li}_2\left(\frac{2(m_{O_s}^2-m_{\tilde{q}}^2)}{m_{O_s}^2-2m_{\tilde{q}}^2+m_{O_s}\tilde{r}^-_{O_s}}\right) - \mathrm{Li}_2\left(\frac{2(m_{O_s}^2-2m_{\tilde{q}}^2)}{m_{O_s}^2-2m_{\tilde{q}}^2-r^{+,4}_{O_s}}\right)\right.$$
$$\left.\left.+\mathrm{Li}_2\left(\frac{2(m_{O_s}^2-m_{\tilde{q}}^2)}{m_{O_s}^2-2m_{\tilde{q}}^2-r^{+,4}_{O_s}}\right) - \mathrm{Li}_2\left(\frac{2(m_{O_s}^2-2m_{\tilde{q}}^2)}{m_{O_s}^2-2m_{\tilde{q}}^2+r^{+,4}_{O_s}}\right) + \mathrm{Li}_2\left(\frac{2(m_{O_s}^2-m_{\tilde{q}}^2)}{m_{O_s}^2-2m_{\tilde{q}}^2+r^{+,4}_{O_s}}\right)\right]\right\};$$

$$A_4\left(m_{\tilde{q}}^2,m_{\tilde{g}}^2,m_{O_s}^2\right) = \frac{m_{\tilde{g}}^2}{6m_{O_s}^2\left(m_{O_s}^2-m_{\tilde{q}}^2\right)}\left\{L_8^2 - L_9^2 + L_{15}^2 + \right.$$
$$+2\left[\mathrm{Li}_2\left(\frac{2(m_{O_s}^2-m_{\tilde{q}}^2)}{m_{O_s}(m_{O_s}+\tilde{r}^-_{O_s})}\right) + \mathrm{Li}_2\left(\frac{2(m_{O_s}^2-2m_{\tilde{q}}^2)}{m_{O_s}^2-2m_{\tilde{q}}^2-m_{O_s}\tilde{r}^-_{O_s}}\right) + \mathrm{Li}_2\left(\frac{2(m_{O_s}^2-2m_{\tilde{q}}^2)}{m_{O_s}^2-2m_{\tilde{q}}^2+m_{O_s}\tilde{r}^-_{O_s}}\right)\right.$$
$$\left.\left.-\mathrm{Li}_2\left(\frac{2(m_{O_s}^2-m_{\tilde{q}}^2)}{m_{O_s}^2-2m_{\tilde{q}}^2+m_{O_s}\tilde{r}^-_{O_s}}\right) + \mathrm{Li}_2\left(\frac{2(m_{O_s}^2-2m_{\tilde{q}}^2)}{m_{O_s}^2-r^{+,4}_{O_s}}\right) - \mathrm{Li}_2\left(\frac{2(m_{O_s}^2-m_{\tilde{q}}^2)}{m_{O_s}^2-2m_{\tilde{q}}^2-r^{+,4}_{O_s}}\right)\right]\right\};$$

$$A_5\left(m_{\tilde{q}}^2,m_{\tilde{g}}^2,m_{O_s}^2\right) = \frac{m_{\tilde{g}}^2 m_{O_s}^2}{4m_{O_s}^2m_{\tilde{q}}^2-8m_{\tilde{q}}^4}L_{12}^2;$$

$$A_7\left(m_{\tilde{q}}^2,m_{\tilde{g}}^2,m_{O_s}^2\right) = \frac{m_{\tilde{g}}^2}{6m_{\tilde{q}}^4\,\tilde{r}^-_{O_s}}\left[m_{O_s}\left(m_{O_s}^2-2m_{\tilde{q}}^2\right)\left(\log\left(\frac{2m_{\tilde{q}}}{m_{O_s}}\right)-L_7\right) + \tilde{r}^-_{O_s}\,r^{+,4}_{O_s}\left(\log\left(\frac{m_{O_s}}{2m_{\tilde{q}}}\right)+L_{10}\right)\right].$$

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Full resummed cross-section

The NNLL resumed cross-section reads as:

$$\tilde{\hat{\sigma}}^{(\mathrm{res})}_{ij\to\tilde{q}\tilde{q}^{(*)}}(N,\{m^2\},\mu^2) = \sum_I \tilde{\hat{\sigma}}^{(0)}_{ij\to\tilde{q}\tilde{q}^{(*)},I}(N,\{m^2\},\mu^2)\left(1+\frac{\alpha_S}{\pi}\,C^{(1)}_{ij\to\tilde{q}\tilde{q}^{(*)},I}(N,\{m^2\},\mu^2)\right)$$
$$\times\,\exp\Big[Lg_1(\alpha_S L)+g_{2,I}(\alpha_S L)+\alpha_S g_{3,I}(\alpha_\mathrm{s} L)\Big]\,.$$

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The NNLL resumed cross-section reads as:

$$\tilde{\hat{\sigma}}^{(\mathrm{res})}_{ij\to\tilde{q}\tilde{q}^{(*)}}(N,\{m^2\},\mu^2) = \sum_I \tilde{\hat{\sigma}}^{(0)}_{ij\to\tilde{q}\tilde{q}^{(*)},I}(N,\{m^2\},\mu^2)\,\left(1+\frac{\alpha_S}{\pi}\,C^{(1)}_{ij\to\tilde{q}\tilde{q}^{(*)},I}(N,\{m^2\},\mu^2)\right)$$
$$\times\,\exp\left[Lg_1(\alpha_S L) + g_{2,I}(\alpha_S L) + \alpha_S g_{3,I}(\alpha_\mathrm{s} L)\right].$$

The NLO and NNLL results are added up through a matching procedure that avoids double counting of the NLO terms [Catani, Mangano, Nason, Trentadue (1996)]:

$$\sigma^{(\mathrm{NLO+(N)NLL})}_{h_1 h_2\to\tilde{q}\tilde{q}^{(*)}}(\rho,\{m^2\},\mu^2) = \sum_{i,j}\int_{\mathrm{CT}}\frac{dN}{2\pi\imath}\,\rho^{-N}\,\tilde{f}_{i/h_1}(N+1,\mu^2)\,\tilde{f}_{j/h_2}(N+1,\mu^2)$$
$$\times\left[\tilde{\hat{\sigma}}^{(\mathrm{res})}_{ij\to\tilde{q}\tilde{q}^{(*)}}(N,\{m^2\},\mu^2) - \tilde{\hat{\sigma}}^{(\mathrm{res})}_{ij\to\tilde{q}\tilde{q}^{(*)}}(N,\{m^2\},\mu^2)\Big|_{(\mathrm{NLO})}\right] + \sigma^{(\mathrm{NLO})}_{h_1 h_2\to\tilde{q}\tilde{q}^{(*)}}(\rho,\{m^2\},\mu^2).$$

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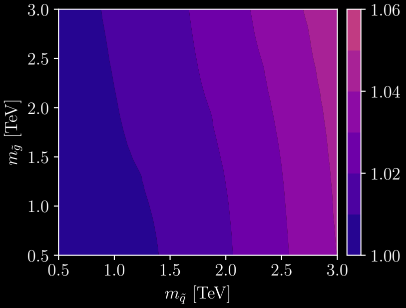
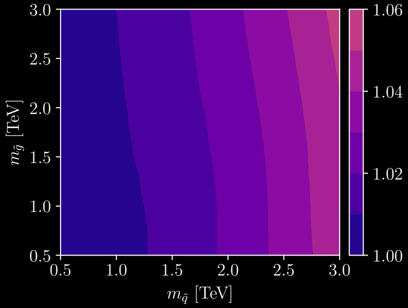
$$K_{\mathrm{NLL}} \equiv \frac{\sigma^{(\mathrm{NLO+NLL})}}{\sigma^{(\mathrm{NLO})}} \qquad \text{with} \qquad m_O = 100\ \mathrm{TeV}.$$



$\tilde{q}\tilde{q}$ MRSSM

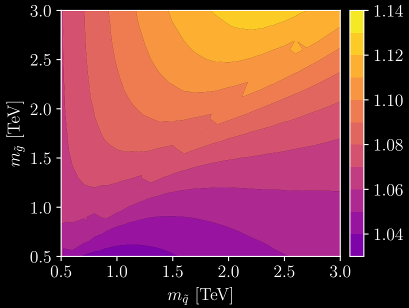


$\tilde{q}\tilde{q}$ MSSM

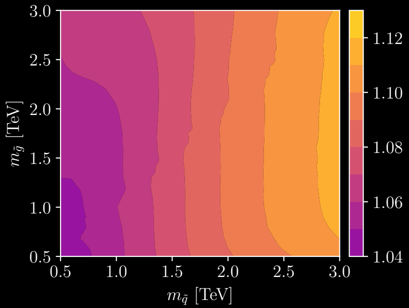
- soft-gluon corrections larger as $m_{\tilde{q}}$ increases;
- corrections of the same size in the two models;

K-factors for $\tilde{q}\tilde{q}^*$

$$K_{\text{NNLL}} \equiv \frac{\sigma^{(\text{NLO+NNLL})}}{\sigma^{(\text{NLO})}} \qquad \text{with} \qquad m_O = 100\ \text{TeV}.$$



$\tilde{q}\tilde{q}^*$ MRSSM

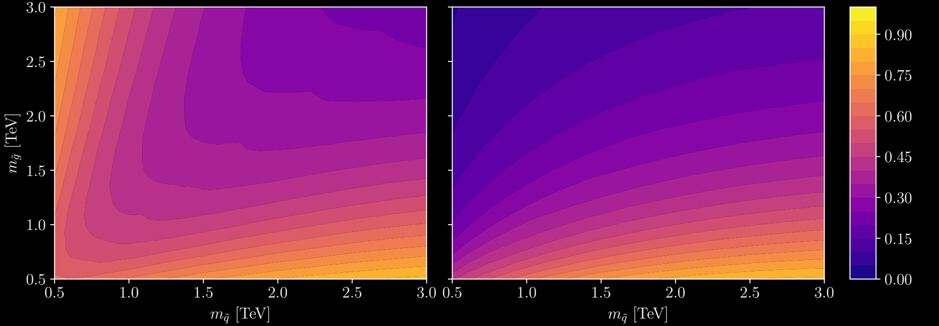


$\tilde{q}\tilde{q}^*$ MRSSM

- soft-gluon corrections larger as $m_{\tilde{q}}$ increases;
- the $m_{\tilde{g}}$-dependece is different;
- corrections of the same order, up to 14% in the MRSSM.

Ratio $\sigma^{\text{MRSSM}}/\sigma^{\text{MSSM}}$

Ratios of MRSSM cross-sections over the MSSM ones at the same accuracy with $m_O = 100$ TeV;



- $\tilde{q}\tilde{q}^*$ at NLO+NNLL (left side);
- $\tilde{q}\tilde{q}$ at NLO+NLL (right side).

σ^{MRSSM} is drastically reduced compared to σ^{MSSM}.

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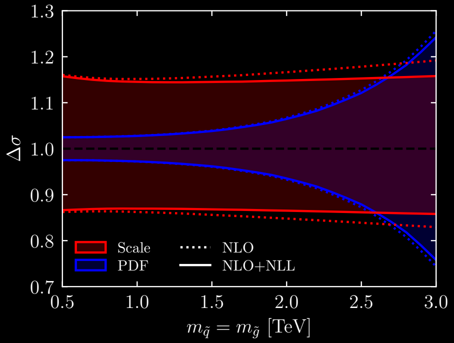
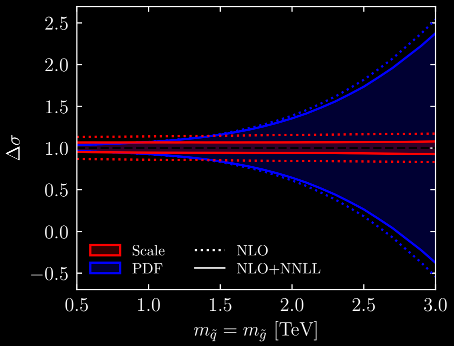
Uncertainties



$\tilde{q}\tilde{q}$ MRSSM



$\tilde{q}\tilde{q}^*$ MRSSM

- By including resummation corrections, the scale uncertainty is reduced;
- PDF errors dominated by quark channel, due to valence quarks luminosity.

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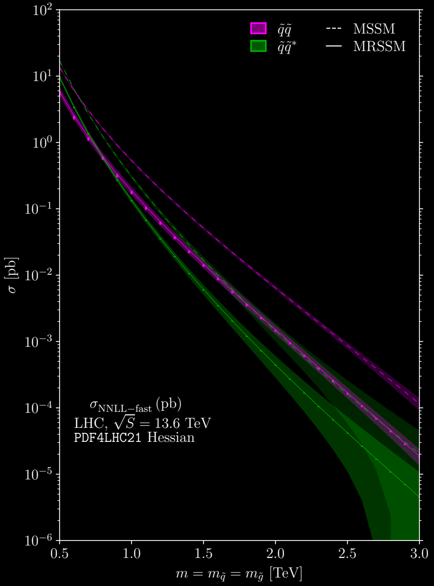
cross-section at NLO+(N)NLL



- Total cross-section for squarks production at NLO+(N)NLL;
- results at $\sqrt{S} = 13.6$ TeV for $m_{\tilde{q}} = m_{\tilde{g}}$ and $m_O = 100$ TeV with PDF4LHC21 PDFs;
- error for scale and PDF+α_S uncertainties;
- one-sided error bars for the change of $m_O = 2$ TeV.

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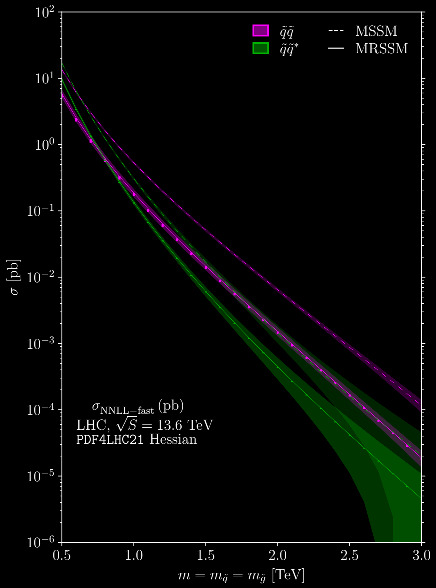

- Precision predictions for squarks production at the LHC in the MRSSM:
  - NLO+NNLL accuracy for $\tilde{q}\tilde{q}^*$;
  - NLO+NLL accuracy for $\tilde{q}\tilde{q}$;
- MRSSM cross sections lower by up to two orders of magnitude in parameter regions of interest:
  - leads to a less stringent limit for $m_{\tilde{q}}$;
  - suppression depends strongly on the overall mass scale as well as on the mass splitting between $\tilde{q}$ and $\tilde{g}$;
- adding soft gluon correction beyond NLO increases the cross section and reduces the theoretical error.

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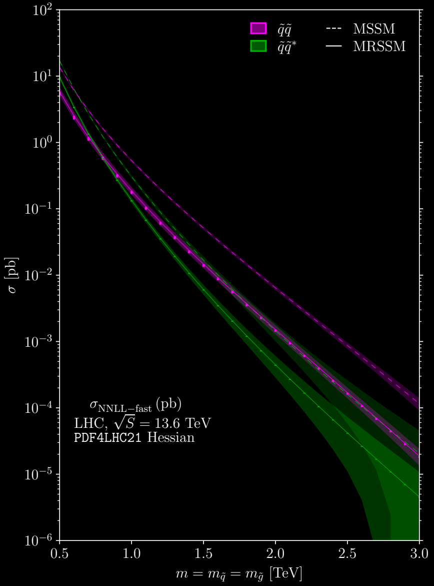

MRSSM (and MSSM) results are included in the NNLL-Fast code [Beenakker, Borschensky, Krämer, Kulesza, Laenen (2016)][Beenakker, Borschensky, Krämer, Kulesza, Laenen, Mamužić, Moreno Valero (2024)]
www.uni-muenster.de/Physik.TP/~akule_01/nnllfast

- $\sqrt{S} = 13, 13.6$ TeV with PDF4LHC21 PDFs.

THANK YOU! 🙃

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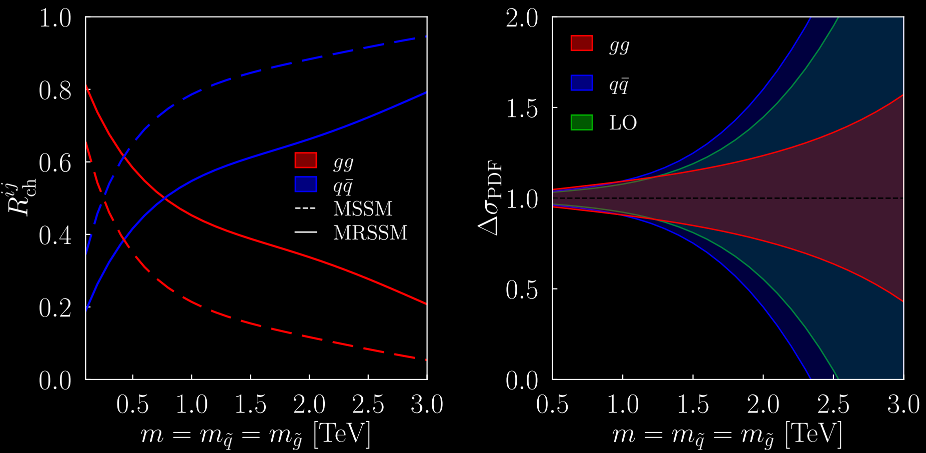

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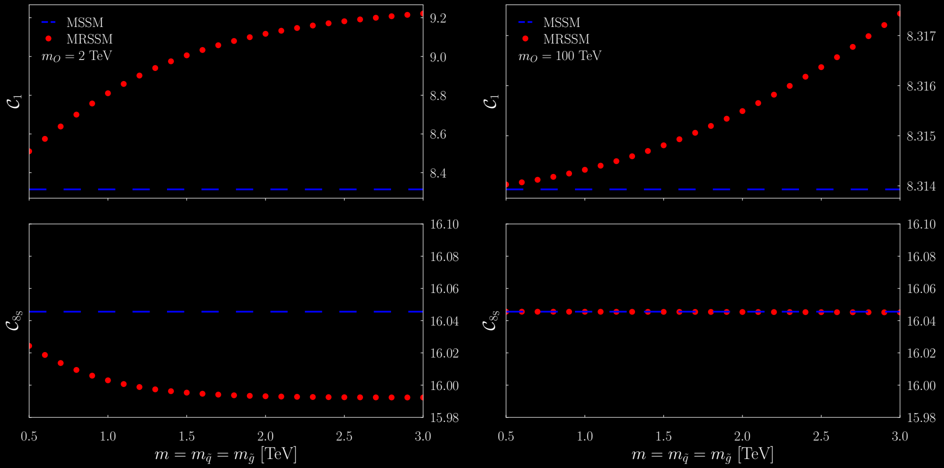

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chiral superfield	R-charge	spin 0	spin $\frac{1}{2}$	$U(1)_Y \otimes SU(2)_L \otimes SU(3)_C$
$\hat{q}$	1	$\tilde{q}$	q	$\left(\frac{1}{6}, \mathbf{2}, \mathbf{3}\right)$
$\hat{l}$	1	$\tilde{l}$	l	$\left(-\frac{1}{2}, \mathbf{2}, \mathbf{1}\right)$
$\hat{H}_d$	0	H_d	$\tilde{H}_d$	$\left(-\frac{1}{2}, \mathbf{2}, \mathbf{1}\right)$
$\hat{H}_u$	0	H_u	$\tilde{H}_u$	$\left(\frac{1}{2}, \mathbf{2}, \mathbf{1}\right)$
$\hat{d}$	1	$\tilde{d}_R^*$	d_R^*	$\left(\frac{1}{3}, \mathbf{1}, \mathbf{3}\right)$
$\hat{u}$	1	$\tilde{u}_R^*$	u_R^*	$\left(-\frac{2}{3}, \mathbf{1}, \mathbf{3}\right)$
$\hat{e}$	1	$\tilde{e}_R^*$	e_R^*	$(1, 1, 1)$
$\hat{S}$	0	S	$\tilde{S}$	$(0, \mathbf{1}, \mathbf{1})$
$\hat{T}$	0	T	$\tilde{T}$	$(0, \mathbf{3}, \mathbf{1})$
$\hat{O}$	0	O	$\tilde{O}$	$(0, \mathbf{1}, \mathbf{8})$
$\hat{R}_d$	2	R_d	$\tilde{R}_d$	$\left(\frac{1}{2}, \mathbf{2}, \mathbf{1}\right)$
$\hat{R}_u$	2	R_u	$\tilde{R}_u$	$\left(-\frac{1}{2}, \mathbf{2}, \mathbf{1}\right)$

vector superfield	R-charge	spin $\frac{1}{2}$	spin 1	$U(1)_Y \otimes SU(2)_L \otimes SU(3)_C$
$\hat{B}$	0	$\tilde{B}^0$	B^0	$(1, \mathbf{1}, \mathbf{1})$
$\hat{W}$	0	$\tilde{W}^\pm, \tilde{W}^0$	$W^\pm, W^0$	$(1, \mathbf{3}, \mathbf{1})$
$\hat{g}$	0	$\tilde{g}$	g	$(0, \mathbf{1}, \mathbf{8})$